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Ink-Jet Printing

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25.1 Introduction

Ink-jet printing refers to any system in which droplets of ink are ejected onto a printing surface to form characters, codes, or other graphic patterns. The ink-jet concept dates from the 1860s, when Lord Kelvin developed the first practical jet for pattern generation. Early commercialization was in the oscillographic recorder area in the 1950s. Since the 1960s, ink-jet developments have focused on computer output, with major contributions made by such scientists as Hellmuth Hertz in Europe (Lund Institute, Sweden) and Richard Sweet (Stanford University) and Steven Zoltan (Brush Instruments) in the United States.

Current commercial products range from printers for direct coding of packages, to high-speed–low-resolution direct mail printers (from Diconix), to graphic arts quality color plotters (from Iris Graphics), to graphic arts quality color plotters (from Hewlett Packard). To address this range of applications, several variants of the technology have been developed. Each approach involves trade-offs among cost, speed, reliability, and print quality, determined by interactions between hardware and supplies.

Ink-jet printing functions include the following:

- Creation of an ink stream or droplets under pressure
- Ejection of ink from a nozzle orifice
- Control of drop size and uniformity
- Control of which drops reach the paper
- Placement of drops on the recording surface

Control of these processes depends on several design variables, such as nozzle size, firing rates, drop deflection methods, and ink viscosity. Changing any variable typically requires adjustments to other system variables, making R&D advances slow and expensive.

Ink-jet printers fall into two basic categories: continuous jet (synchronous) and impulse jet (drop-on-demand). Most early development took place in the continuous jet arena, but recent emphasis has shifted to the less complex (and therefore less costly) drop-on-demand approaches.

25.2 Continuous Jet Printing

Continuous ink-jet systems operate by forcing pressurized ink in a cylinder through nozzles in a continuous stream. Nozzle diameters range from 3 to 0.5 mil; the smallest nozzles can require up to 600 psi of pressure to eject the ink. The ink stream is unstable, breaking into individual droplets either naturally

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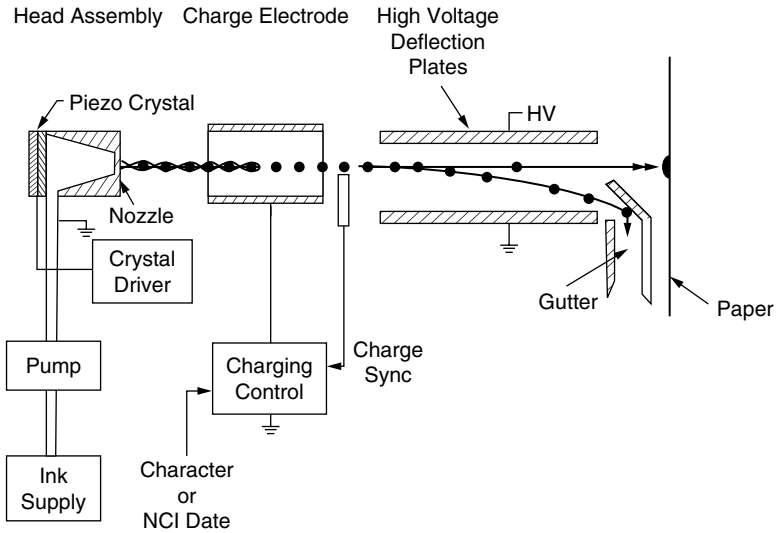

FIGURE 25.1 Continuous ink-jet print system. (From Sweet, R. G. et al., U.S. Patent 3,373,437.)

or through some applied stimulation such as ultrasonic vibration. Electrostatic deflection is used to control the droplets, which either reach the page in the desired pattern or are deflected into a "gutter" or "catcher" (see Figure 25.1). Deflection can be binary or variable.

Continuous jet printers either recycle or discard the unused ink, which can account for up to 98% of the generated droplets. Although preferable in terms of supply costs, recycling adds substantially to system complexity because of the need for pumps and ink purity safeguards (such as filters and solvent balance controls).

Continuous ink-jet systems are capable of very high speed printing, with drop frequency rates sometimes in excess of 100 kHz. At these rates, it is difficult to control individual droplets: their tendency to combine into larger drops leads to print quality concerns. Ideally, however (i.e., when controlled), this tendency can yield enhanced image quality: because each printed pixel may be composed of multiple droplets, it is possible to control the pixel size, resulting in halftoning capabilities. High-resolution halftoning cuts the speed of continuous ink-jet systems considerably, however.

25.3 Impulse Jet (Drop-On-Demand) Printing

In contrast to continuous jet printers, drop-on-demand ink delivery systems create drops only as needed, thereby eliminating the need to control excess droplets. These systems are inherently binary; either a drop is ejected for placement on the receiver sheet or it is not.

Most of the system complexity of an impulse jet printer is in the printhead because no recycling mechanism is required. Typically, an impulse jet printhead has a pressurized reservoir of ink held directly behind a nozzle or orifice. When activated by electrical pulses, drops of ink are ejected and directed to the page.

There are two basic methods of activating the ink droplets. The earliest impulse jet models used piezoelectric transducers that squeeze the ink chamber or impulse the chamber at one end. Figure 25.2 shows a schematic of the piezoelectric approach. The alternative approach, thermal activation of ink drops, is gaining popularity as a result of developments by Hewlett Packard and Canon. A heater creates a bubble of ink vapor that forces ink drops from the nozzle (Figure 25.3).

Most newer ink-jet printers use impulse jet technologies to address general-purpose printing applications. Advantages include mechanical simplicity, low hardware cost, and simplified logic. However, there are disadvantages as well: drop-on-demand printers are more sensitive to shock and vibration and have

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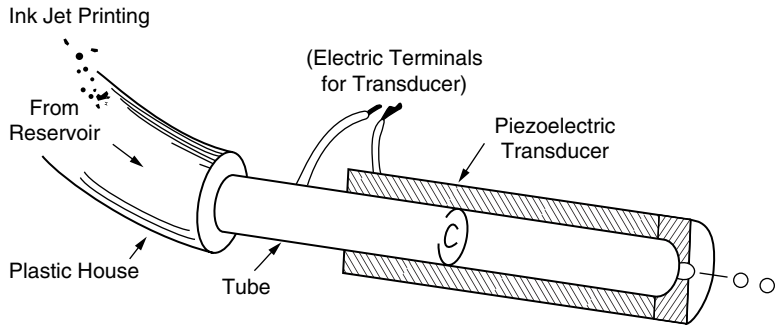

FIGURE 25.2 Piezoelectric impulse jet nozzle. (From Zoltan, S., U.S. Patent 3,683,212.)

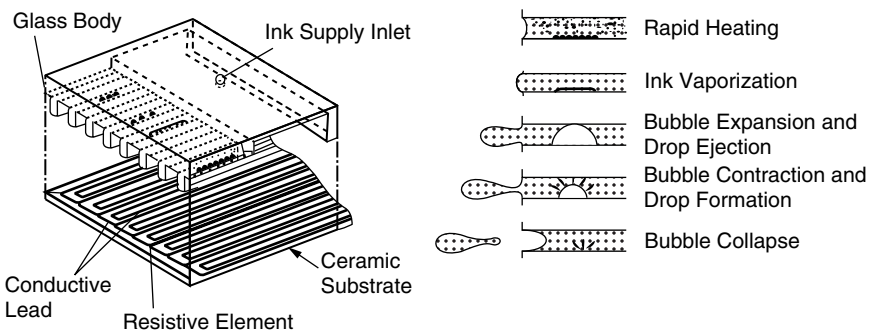

FIGURE 25.3 Thermally activated Canon impulse jet printhead. (From Jaffe, A. B. and Mills, R. N., "Color hardcopy for computer systems," in *SID Proceedings*, Vol. 24/3, 1983, pp. 219–234.)

slower dot ejection rates (sometimes as low as 3 kHz). In addition, market acceptance has been slow, partly because of early reliability problems due to nozzle clogging from dried ink or paper dust.

25.4 Ink-Jet Inks

Ink-jet printer design requires close matching of mechanical components, imaging inks, and, in many cases, the receiver materials. Ink chemistry is a critical link, determining diverse attributes such as viscosity, drop flight, corrosive properties, surface tension, drying time, dot shape, optical density and edge acuity, fade resistance, and compatibility with printing surfaces.

Traditionally, inks have been liquid, with a water or solvent base. Continuous jet inks are usually based on one of a wide range of solvents, which permit fast drying on both porous and nonporous substrates. Impulse-jet printers require high boiling point inks, usually water based. Several recently commercialized or wax materials are melted for ejection but solidify immediately on the receiver. Proponents claim that solid inks solve print quality problems from undesirable wicking of ink into paper fibers, although at the cost of considerable system complexity and embossed output, which is objectionable to some.

Ink formulation involves a series of trade-offs, depending on type of printing system and the requirements of target applications. For instance, in impulse jet systems, where danger of nozzle clogging exists, inks must not dry within the nozzle; yet once ejected, they must dry fast enough on the paper to minimize feathering in the paper fibers. The difficulty of this undertaking is evident from the fact that few current ink-jet printers offer true plain paper printing; most systems require special clay-coated papers to prevent wicking, and this is a drawback in office environments.

Coloring agents in ink-jet inks also present a challenge. Because pigment particles could make the ink too viscous and might cause clogging or undue wear, dyes are used instead. Resulting problems include lack of optical density (a grayish hue) and archival problems due to a tendency to fade.

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The success of ink-jet printing depends on developments that match systems' capabilities to printing requirements. Ink-jet products have been highly successful for years in environments where speed and surface independence have been more important than image quality (e.g., for package coding and direct mail). Recent improvements in reliability, resolution, paper tolerance, and coloring agents could ultimately bring high quality office printing and color applications within reach.

Ink-jet has been among the most challenging output technologies to perfect, with enormous R&D outlays and a long history of failed products. However, recent progress suggests that the allure of ink-jet as a potentially elegant, low cost printing solution will finally be justified.

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